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Does Isometric Shoulder Strength Correlate to Shoulder Endurance?

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Abstract

Context: Shoulder strength in relation to endurance is an understudied topic in the field of sports medicine. Shoulder injuries are common and often result from the repetitive nature of overhead sports. The benefit of a strong correlation would ultimately help aid rehabilitation and injury prevention programs for overhead athletes.

Objective: The purpose of this study is to determine if there is a direct correlation between rotator cuff strength and shoulder endurance for internal and external rotation

Design: Qualitative study

Participants: Twenty-three male collegiate students between 18-30 years old without a shoulder injury or pain within the last 12 months.

Data Collection and Analysis: Subjects were sampled through convenience sampling and were screened to meet inclusion criteria. The subject's dominant arm was tested for both strength and endurance of internal rotation of subscapularis and external rotation of infraspinatus and teres minor. Subjects were randomly assigned to testing order. Tools included a hand-held dynamometer to test strength and a pressure biofeedback unit to test endurance. Measurements for strength and endurance were tested in three positions of shoulder abduction (0, 30, and 90 degrees) for internal rotation and external rotation. Data was evaluated through a Pearson correlation and Spearman Rank correlation.

Results: Results showed overall weak correlation between shoulder endurance and strength. The highest correlations were at 45 degrees shoulder abduction and external rotation (r=0.38) and 45 degrees with internal rotation (r=0.21). The lowest correlation was at 0 degrees of internal rotation (r=-0.03)

Conclusion: There were not enough significant results to suggest a correlation between shoulder strength and endurance. This study opened up to further research with modifications in the approach and use of more standardized devices of measurement.

Keywords: Rotator cuff; Endurance, Strength; Overhead Athlete; Training Program

Introduction

Shoulder injuries are common in overhead athletes due to the repetitive nature of their sport. The shoulder undergoes tremendous stress with overhead motions which is why dynamic glenohumeral stability is of great importance in this population. Dynamic glenohumeral stabilization is generated by the compressive forces of the rotator cuff muscles. The rotator cuff muscles keep the humeral head centered in the glenoid to offset any distractive forces allowing for optimal joint kinematics. During overhead throwing, increased rotator cuff activity is required throughout the motion to resist the forces placed on the shoulder [1]. During arm cocking, peak rotator cuff activity is 49-99% of a maximum voluntary isometric contraction (MVIC) in baseball pitching and 41–67%MVIC in football throwing. During arm deceleration, peak rotator cuff activity is 37–84%MVIC in baseball pitching and 86–95%MVIC in football throwing. Sufficient strength of the rotator cuff muscles is essential in these athletes; however, shoulder endurance is the strongest factor associated with injuries in this population due to their repetitive and pro-longed overhead activity [2].

Overhead athletes are highly susceptible to performing with shoulder fatigue. In baseball pitchers, rotator cuff fatigue is observed after 60 pitches, but the average number of pitches per game is around 119, including warm up and bullpen pitches [3]. Once fatigued, these athletes have an increased risk for injury as their joint mechanics become altered. In one study, researchers found that arm fatigue in pitchers was associated with elbow pain as it resulted in a compensatory overuse of the elbow joint. Another study investigated scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol. After performing the fatigue protocol, subjects demonstrated less external rotation of the humerus and posterior tilt of the scapula, reducing the size of the subacromial space [4]. Another study found a decrease in shoulder external rotation and an increase in distraction forces at both the shoulder and elbow and an increase in horizontal adduction torque once the pitcher was fatigued. These changes in mechanics put greater load and stress onto the rotator cuff and other structures that over time produce different pathologies [5].

The substantial volume of throwing expected of these athletes demonstrates the importance of endurance training of the rotator cuff muscles in pre-season training and post-injury rehabilitation [5]. It is important for overhead athletes to be able to resist shoulder fatigue, however, most overhead athletes exhibit significant weakness of the supraspinatus and external rotators of their throwing arm, which could play a role in their endurance. The muscles of the rotator cuff work together to maintain optimal alignment of the humeral head in all planes of motion for efficient dynamic stabilization and motor control at the shoulder [6]. Weakness can lead to poor mechanics and coordination resulting in greater energy expended, predisposing the athlete to fatigue more quickly. Stronger athletes are more efficient in their movements, leading to enhanced endurance capabilities as a result of performing less work to accomplish a given task. An increase in strength has also been shown to reduce the amount of muscle activated for a given load, decreasing the amount of motor units needed to produce the same force, ultimately increasing an athlete's endurance. For these reasons, there may be a correlation between rotator cuff strength and endurance [7].

There are many studies examining the relationship between strength and endurance, however, there are limited studies investigating this relationship in the shoulder. When comparing strength to absolute endurance (how much work one can do with a specific load before fatiguing) most agree there is a positive correlation. For example, stronger individuals can maintain a higher level of strength for 100 seconds compared to weaker individuals [8]. However, when comparing strength with relative endurance (how much work one can do with a load relative to one's maximum capacity before fatiguing) there seems to be a negative correlation. Individuals with greater strength fatigue more quickly as they maintain a lower percentage of their strength compared to weaker individuals. These findings are similar to Rohmert's fatigue curve, that demonstrates the closer an athlete performs at their maximum strength, the faster they will fatigue as more muscle fibers are recruited to generate a more forceful contraction. However, the more strength an athlete gains, the less muscle units are needed to perform the same task at the same level, inevitably increasing their endurance [9]. Another study evaluated the strength, endurance and fatigue response of rotator cuff muscles. Infraspinatus exhibited the highest strength followed by teres minor and supraspinatus. The authors found small variations in endurance times with supraspinatus having the shortest, however, the numbers were not significantly different. Due to the limited research, this study aimed to investigate the relationship between isometric strength and endurance in the shoulder [10].

There are many ways to measure strength of different muscle groups in the body. Many studies provide significant evidence that hand-held dynamometry is a superior measure of isometric strength, especially on muscle groups such as the rotator cuff and shoulder complex [11]. It has been found that when studies used hand-held dynamometry for a measurement of isometric strength, it proves to be most reliable when the examiner has at least ten years of experience. Hand-held dynamometry also demonstrated to have high intra-rater and inter-rater reliability when compared to an externally fixed device. Another strength of this method of analysis is its practicality, cost, and portability when compared to isokinetic devices [12].

Positioning of the subject as well as positioning of the examiner is another imperative concern to accurate and reliable results. Subject positioning will hinder or enhance the probability of compensation patterns and take away from the muscle group under direct analysis. A study by Holt [13]. specified that positioning the feet shoulder width apart, knees and hips slightly flexed, elbow flexed to 90o at side but not touching the body, and a neutral wrist would isolate rotational forces of the shoulder without excessive adduction or abduction. Other studies tested shoulder internal and external rotation against a hand-held dynamometer in sitting and supine and produced reliable results against other strength testing devices. Subject positioning has more variation as it relates to the population tested and the functional demands of that group, whether it be sport or related pathology [14].

When testing shoulder endurance, there is limited literature on the nature of this measurement. A study in 2015 used pressure biofeedback units (PBU) as a training mechanism for postural musculature endurance and proprioception, but not often a measure of muscular endurance to failure [15]. There is also a lack of research contributing towards use of PBUs on the shoulder joint. However, evidence from the literature suggests that this mechanism may be an accurate implementation for measurement of muscular endurance of the rotator cuff and shoulder complex. The 2015 study used PBUs to train muscular endurance of the deep cervical flexors (DCF) as it relates to forward head posture in college students [16]. They found an increase in muscular endurance and cervical mobility after six weeks of PBU training when compared to the conventional DCF strengthening protocol. Another study used PBUs in conjunction with superficial EMG's on knee extension and found positive correlation of activity levels of the quadriceps, proving that PBUs are reliable in clinical practice for proprioceptive evaluation. Much of this data is supportive that pressure biofeedback units are a reliable device to measure and train endurance when used on a variety of muscle groups, and should be capable of the same when implemented on the shoulder joint [17].

Given the excessive loads placed on the shoulder of overhead athletes and their high risk of injury, it is important to encourage proper training and be able to identify risk factors for shoulder injuries [18]. Most injuries in this population are related to poor muscle endurance, however, there are limited studies that functionally measure shoulder endurance and very little research has been done looking at the relationship between rotator cuff endurance and strength. For this reason, this study aimed to generate a correlation between shoulder internal and external isometric strength and endurance, which would ultimately help aid in rehabilitation and injury prevention programs for overhead athletes [19]. The hypothesis is that an increase in shoulder internal and external isometric strength will directly correlate with longer bouts of shoulder endurance.

Materials and Methods

A cross sectional study was performed comparing the subjects dominant arm endurance against strength of the rotator cuff muscles, specifically the internal and external rotators in varying degrees of abduction. An Institutional Review Board form was submitted and approved. The study consisted of two testing stations; one for strength and the other for endurance. Subjects were randomly assigned to which testing station they would begin at upon their arrival. One experimental tester was used at each station to control for interrater reliability. An extra tester was placed at each station to observe and correct for any compensations seen from the subjects as additional muscles may be activated during the test including the pectoralis major and/or the latissimus dorsi, which would cause possible compensatory patterns [20].

Subjects were collected through convenience sampling by placing flyers around a college campus as well as word of mouth. Inclusion criteria consisted of male collegiate students who are 18-30 years old. Exclusion criteria included anyone who had a shoulder injury or pain within the last 12 months. Upon arrival subjects completed a medical questionnaire and a written consent form to participate. The medical questionnaire included age, height, weight, birthdate, and a brief medical screen. Eligibility was confirmed upon written consent. The final sample size included subjects [21].

At the strength station, strength was measured using a hand-held dynamometer placed just proximal to the wrist joint line. Subjects were positioned with both feet on the floor half seated, hips at around 45° flexion, off the corner of a table. Six different measurements were recorded for strength. In all measurements, the elbow was flexed to 90°. The shoulder was tested in three different degrees of abduction;

0°, 45°, and 90°. Internal and external rotation was taken at each of these three shoulder positions. For the 0° shoulder abduction and 90° elbow flexion (0°/90°) position a small towel roll was placed under the elbow (Figure 1).

Figure 1: Figure 1a is depicting the position for strength external rotation 0/90. Figure 1b is depicting the position for strength internal rotation 0/90.

For 45° shoulder abduction and 90° elbow flexion (45°/90°) position a larger towel roll was placed under the arm and measured to achieve the 45° abduction (Figure 2).

Figure 2: Figure 2a is depicting the position for strength external rotation 45/90. Figure 2b is depicting the position for strength internal rotation 45/90.

Lastly, for the 90° shoulder abduction and 90° elbow flexion (90°/90°) position the shoulder was also externally rotated 90°creating a more functional position and an observational researcher placed their hand below the subject's elbow (without contact) to prevent dropping below 90° (Figure 3).

Figure 3: Figure 3a is depicting the position for strength external rotation 90/90. Figure 3b is depicting the position for strength internal rotation 90/90.

For strength, three measurements were taken at each position and the mean of the three scores were used for data analysis. A one-minute rest was given between each position change. The order of positions tested was different and randomized for each subject [22].

For endurance the same six positions were tested. The 0°/90° endurance (Figure 4) and 90°/90° endurance (Figure 5) positions were performed in a doorway and 45°/90° was taken with the arm placed in a specially made box that ensured a 45° angle (Figure 6).

Figure 4: Figure 4a is depicting the position for endurance external rotation 0/90. Figure 4b is depicting the position for endurance internal rotation 0/90.

Figure 5: Figure 5a is depicting the position for endurance external rotation 90/90. Figure 5b is depicting the position for endurance internal rotation 90/90.

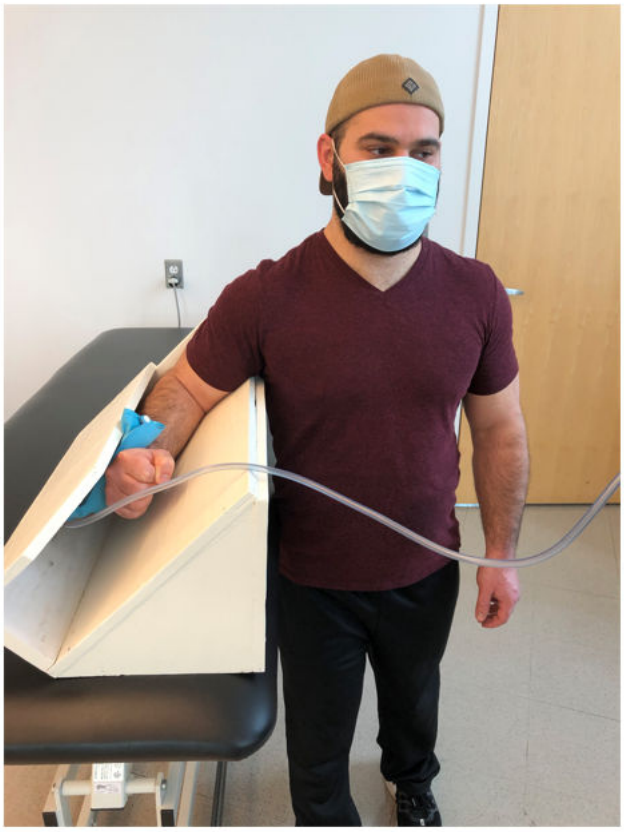

Figure 6: Figure 6a is depicting the position for endurance external rotation 45/90. Figure 6b is depicting the position for endurance internal rotation 45/90.

The measurements for endurance were taken using a PBU placed between the wall/box and just proximal to the wrist joint to avoid compensation from wrist flexion or extension. Subjects were informed of a 10-mmHg range to hold pressure within. Once the subject hit the range the experimenter began timing on a stopwatch and stopped the time once they fell out of the range. The subject was able to watch the pressure while testing to keep within the range. Pressure ranges used with the PBU were determined based on previous documented PBU studies and experiments to pick a range for each position. The designated ranges were 50-60 mmHg for 0°/90° ER and 70-80 mmHg IR, at 50-60 mmHg for 45°/90° ER and 70-80 mmHg IR, and then 20-30 mmHg for 90°/90° ER and 50-60 mmHg for IR. Subjects were positioned to stand tall using proper posture with a heel to toe stance shoulder width apart for each position. Each measurement was taken once with a one-minute rest between each position. The position testing order was randomized for each subject. There was a ten-minute rest period between the strength and endurance station to avoid fatigue. The purpose of the chosen testing positions was to measure the functional position of throwing, at approximately 90 degrees of abduction, as well as testing these same muscles when they are activated at different lengths. At different muscle lengths, there are varying degrees of actin myosin cross bridges creating different force production. By testing in the matter described previously, it allows comparison at the 90-degree throwing position to where the subjects are able to create their maximum force and see if this information can be applied into a training program [23].

Measurement tools included a hand-held dynamometer (HHD) and a pressure biofeedback unit (PBU). The HHD used was the microFET3 and the unit of measurement was taken in pounds. Accuracy of measurement of this specific device is within 1%. This instrument has shown good reliability with repeat trial consistency and validity when specifically testing the strength of intrinsic hand muscles and all other muscles. A study was performed to test the absolute and relative reliability and validity of a HHD on eccentric strength of the shoulder and concluded the intratester reliability was excellent (0.879 and 0.858) and intertester reliability was good. It also reviewed validity and looked at the correlation between the HHD and a Biodex isometric measure and data showed good validity with a Pearson correlation coefficient of 0.78. A HHD is also a common tool used in studies measuring strength of the rotator cuff and shoulder muscles. The PBU has shown positive reliability and validity when testing other muscles but there is no documentation yet when testing the rotator cuff. Number ranges and protocols used in a study that measured the endurance of the deep cervical flexors with a PBU were referenced and used those to adjust and base the testing off [24].

Data Analysis

Normality of data was checked by performing a Shapiro-Wilk test. Descriptive statistics were calculated to present the characteristics of the participants. Continuous data were expressed as mean and standard deviation, and categorical variable was expressed by percentages and number of participants. The correlation between correlations between shoulder endurance and shoulder strength was calculated using Pearson correlation coefficient for all variables, except for Internal Rotation at 0° and External Rotation at 90°, in which Spearman rank correlation coefficient was used. The significance level was set at $P < 0.05$. The Intraclass correlation coefficient (ICC) was measured for the handheld dynamometer strength testing to measure error of the examiner and was averaged to be 0.912. Intraclass correlation coefficients (ICCs) were calculated to determine the intra-rater reliability of isometric strength tests taken from all participants of the study. The ICCs were interpreted as excellent (greater than 0.90), good (0.75–0.90), moderate (0.50–0.75), or poor (< 0.50). All collected data was analyzed with SPSS (version 26; IBM Corp. Armonk, NY) [25].

Results

There were 23 male subjects in this study with an average age of 23.1 ± 2.0 years. The average height was 1.78 ± 0.1 meters, average weight was 75.3 ± 10.0 kilograms, and average body mass index was 23.7 ± 2.5. The subject demographics and characteristics are shown. Twenty of the subjects were right hand dominant and three were left hand dominant. This shows the average endurance results using a Pressure Biofeedback Unit (PBU) as well as the average strength results using a Handheld Dynamometer (HHD) (Table 1).

Age (years)	**23.1 ± 2.0**
Height (m)	1.78 ± 0.1
Weight (kg)	75.3 ± 10.0
BMI	23.7 ± 2.5
Dominant Hand	
Right	86.9% (n=20)

Left	13.1% (n=3)

Table 1: Subject Characteristics.

The average endurance length (in seconds) by the subjects for Internal rotation were 31.3 + 23.1 (at 0° abduction, 90° elbow flexion), 53.8 + 34.4 (at 45° abduction, 90° elbow flexion), and 80.8 + 58.6 (at 90° abduction, 90° elbow flexion, 90° elbow external rotation). The average endurance length (in seconds) by the subjects for External rotation were 68.2 + 40.5 (at 0° abduction, 90° elbow flexion), 49.4 + 30.8 (at 45° abduction, 90° elbow flexion), and 45.2 + 32.4 (at 90° abduction, 90° elbow flexion, 90° elbow external rotation). The average strength (in pounds of pressure) by the subjects for Internal rotation were 41.2 + 9.5 (at 0° abduction, 90° elbow flexion), 45.1 + 10.7 (at 45° abduction, 90° elbow flexion), and 21.2 + 4.7 (at 90° abduction, 90° elbow flexion, 90° elbow external rotation). The average strength (in pounds of pressure) by the subjects for External rotation were 30.4 + 4.8 (at 0° abduction, 90° elbow flexion), 32.0 + 4.7 (at 45° abduction, 90° elbow flexion), and 25.8 + 4.8 (at 90° abduction, 90° elbow flexion, 90° elbow external rotation) (Table 2).

Endurance (seconds)	
PBU IR 0	31.3 + 23.1
PBU IR 45	53.8 + 34.4
PBU IR 90	80.8 + 58.6
PBU ER 0	68.2 + 40.5
PBU ER 45	49.4 + 30.8
PBU ER 90	45.2 + 32.4
Strength (pounds of pressure)	
Strength HHD IR 0	41.2 + 9.5
Strength HHD IR 45	45.1 + 10.7
Strength HHD IR 90	21.2 + 4.7
Strength HHD ER 0	30.4 + 4.8
Strength HHD ER 45	32.0 + 4.7
Strength HHD ER 90	25.8 + 4.8

Table 2: Average of Pressure Biofeedback Unit (PBU) Endurance and Handheld Dynamometer (HHD) Strength.

The analysis determined an overall weak correlation between shoulder endurance and shoulder strength. The correlation coefficient was interpreted as strong (0.70-0.89), moderate (0.40-0.69), weak (0.10-0.39), and negligible (0.00–0.10).26 The highest correlation was observed with 45° of shoulder external rotation (r=0.38, P=0.07), followed by 45° of shoulder internal rotation (r=0.22, P=0.30), 90° of shoulder internal rotation (r=0.21, P=0.33), 0° of shoulder external rotation (r=0.08, P=0.69), and at 90° of shoulder external rotation (r=0.08, P=0.70). The lowest correlation was observed with 0° internal rotation (r=-0.03, p 0.88) (Table 3).

	Correlation (r)	**P-value**
Internal rotation 0o	-0.03	0.88
Internal rotation 45o	0.22	0.3
Internal rotation 90o	0.21	0.33
External rotation 0o	0.08	0.69
External rotation 45o	0.38	0.07
External rotation 90o	0.08	0.7

Table 3: Results of correlation between Endurance *vs* Strength.

Discussion

Shoulder injuries are common in overhead athletes due to the significant and repetitive stress placed on the glenohumeral joint. Sufficient strength and endurance of the rotator cuff muscles are needed for optimal joint mechanics and prevention of fatigue, to decrease the risk of injury. The aim of this study was to provide insight on the relationship between shoulder strength and endurance, to ultimately help aid in rehabilitation and injury prevention programs for this population. The expected outcome was to find longer displays of endurance on subjects who had stronger isometric contractions. This is important in overhead athletes as most of their injuries are related to poor muscle endurance, resulting in their maintenance and rehab programs to focus on endurance training. However, little evidence was found to fully support our hypothesis as a weak correlation between shoulder internal and external isometric strength and endurance was found [26].

The results are similar to the limited studies that examine the relationship between shoulder strength and endurance, despite contradictory literature. The literature indicates maximum strength is related to endurance capabilities. Strength training has been shown to produce increases in endurance among trained subjects and athletes. Stronger athletes are more efficient in their movements so they expend less energy leading to better endurance. However, similar to the findings in this study, other studies have found poor relationships between strength and endurance in the shoulder. In one study, researchers compared isometric strength and endurance of the rotator cuff muscles in healthy males using isokinetic maximum voluntary contractions and surface electromyography. The authors found small and insignificant variations in the endurance times of rotator cuff muscles despite strength differences. However, this study only used EMG sensors on the rotator cuff muscles so it cannot be determined if other muscles were activated and had an influence on the results. Another study evaluated the relationship between concentric shoulder endurance and isometric shoulder strength. Declève. also found a weak correlation between rotational shoulder endurance and strength. Nonetheless, this study lacked homogeneity between their measurements as they compared different types of contractions with different types of resistance. These results along with the data from this study, demonstrate that shoulder endurance does not correspond directly to an individual's strength. The weak correlation suggests that overhead athletes must include both strength and endurance exercises in their training to ensure proper biomechanics and injury prevention. Coaches and clinicians must also take both measurements for screening tools for injury risk as one does not predict the other. However, this weak relationship could be due to compensatory muscle activation and a lack of standardized protocols.

A limit in the study was the lack of ability for examiners to observe internal compensations while the subjects were being tested.

Positionally corrections were made as they were observed, but it was unclear if the internal and external rotation were coming directly from the rotator cuff muscles. One way to control for this would have been through a surface EMG biofeedback unit. Studies show that with a visual representation, subjects have been able to isolate and train one muscle. A study performed looking at infraspinatus and posterior deltoid activation showed that with an EMG on both muscle groups the subjects were able to drastically decrease the use of the posterior deltoid and focus on infraspinatus activation when performing external rotation. The study also compared a control group with no visual biofeedback. It showed that the ratio of posterior deltoid to infraspinatus favored the use of the deltoid muscle in performing the action compared to with feedback. The assumption can be made that there were compensations of other muscles being activated in this study which could have potentially skewed the data.

Conclusion

Due to lack of literature on utilization of PBU's to measure endurance in the shoulder, the protocols of this study lacked standardization. Multiple pressure ranges were subjectively developed contingent upon the angle of the shoulder and motion tested. A study used a PBU to measure the muscular endurance of deep neck flexors and their effect on forward head posture. They were able to measure endurance at 50 mmHg in the supine position. Measurement of the deep neck flexors in the supine position decreased risk of compensations from other muscle groups, which this study was unable to verify as previously discussed. A pilot study was done to choose the pressure in Kang's research, while this study's standards were chosen by the researchers creating bias. The variable pressure ranges in conjunction with the diverse anthropometrics of the subjects created discrepancies of scores and low correlation.

The test of endurance was a prolonged isometric force produced by the muscle. Throwing is a dynamic action whereby an isokinetic force is produced. However, studies have showed that overhead throwing, requires isometric contraction to stabilize the shoulder. During arm cocking, peak rotator cuff activity is 49-99% of a Maximum Voluntary Isometric Contraction (MVIC) in baseball pitching and 41–67% MVIC in football throwing. During arm deceleration, peak rotator cuff activity is 37–84% MVIC in baseball pitching and 86–95% MVIC in football throwing. Peak rotator cuff activity is also high is the windmill softball pitch (75–93% MVIC), the volleyball serve and spike (54–71% MVIC), the tennis serve and volley (40–113% MVIC), baseball hitting (28–39% MVIC), and the golf swing (28–68% MVIC). Despite the differences between isometric and dynamic movements, there is evidence that shoulder isometric strength is correlated with throwing velocity. While isometric strength training is not as functional for throwing as eccentric control of the rotator cuff would be for throwing mechanics, isometrics is an important foundation for muscles to be able to handle eccentric load. Additionally, there is currently a lack of functional or lower cost tests for measuring endurance. For these reasons, isometric endurance testing is considered functional for overhead athletes.

This study is also not without additional limitations. First, the subject population was contained to male subjects between the ages of 18-30 years old. Due to the small sample size and the narrow demographic of the participants, in order to increase the study's validity, larger sample sizes with a more diverse population of males and females of varying ages will need to be studied. There were limitations in the reliability. Another limitation related to how the subjects responded to the task. This could have been avoided by utilizing an electromyographic biofeedback unit on each subject to ensure they were not compensating with muscles that were not specifically targeted in order to complete the test. This information would give immediate feedback regarding what muscles are being utilized and which ones are not. Holding a session prior to data collection instructing the subjects how to perform within the testing protocol, would have aided in decreasing the possibility of compensatory muscle action. The final limitation relates to the varying standards of protocol utilized in testing. Using multiple pressure ranges may have limited the researchers on standardizing the PBU protocol.

The results of this cross-sectional analysis of shoulder strength and endurance ratios did not suggest a significant correlation between the two. The highest correlation was shown with external rotation at 45° of abduction, which indicates a functional position is where most strength and endurance is seen in conjunction. Whereas when the shoulder is put in positions where it is less often used, strength, endurance, or both, may be diminished contingent upon the individual. There is not enough data to suggest how shoulder strength or endurance could affect performance, injury, or training. This under-researched topic would benefit from further exploration with modifications suggested from the limitations of this study.

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